Climatological investigation and modeling of wet snow events severe to the high voltage electrical transmission system and integration of the results into the operational work

Theses of the PhD dissertation

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Introduction and objectives

Atmospheric icing can be divided into two groups: in-cloud icing (soft and hard rime) and precipitation icing (freezing rain and wet snow). My study focuses specifically on wet snow. The formation of wet snow needs special circumstances. While the snowflakes fall through a slightly positive temperature layer, they partly melt and liquid water appears in their crystal structure. The optimal liquid water content of the snowflakes is between 12–15% (Sakakibara, 2007). If the temperature interval near the ground ranges from –0.5 °C to +2 °C, the partly melted snowflakes can effectively adhere to obstacles due to adhesion forces. The mass of accumulated snow can cause fracture damage in the forests, interruptions and delays on the railway and power outages in thousands of households. The initial conditions of wet snow accumulation have some unresolved issues, such as the criterion of rotation of the wire or the microphysical properties of snow crystals. If once the accretion begins, also the accumulation process is complex, because the sticking efficiency (ß) and the density of the wet snow sleeve must be parameterized during the process.

The main objective of my work is to investigate the statistical-climatological background of wet snow in Hungary, creating a wet snow forecasting system using both operational numerical weather prediction models (ECMWF, AROME, ALADIN, WRF) and ensemble methods (AROME-EPS). I wanted to find the answers to the followings: 1. How is the vertical profile during wet snow events? 2. How are the 50- and 100-year return levels of wet snow? Which levels and trends of Ice Classes do the meteorological stations characterize? 3. How can the wet snow forecast be integrated into operative work?

Methodology

The study consists of 3 parts:

1. **Investigation of vertical stratification:** the vertical condition of the atmosphere rules the formation of wet snow, so 36-year long sounding dataset (1980–2016) was used on 1000, 925, 900, 850, 800 and 700 hPa pressure levels in Budapest-Pestszentlőrinc and Szeged stations. After selecting data, 1315 cases have met the criteria system, which is a properly high number to perform statistical investigations. R open-source

statistical program was used for the calculations and visualization (R Development Core Team, 2008).

2. **Extreme value analysis:** the Peak-Over-Threshold (POT) method is the most appropriate to determine the return level value of accumulated wet snow mass (Coles, 2001). First, two graphical methods were used to determine the thresholds: Mean Residual Life plot (MRL) and Dispersion Index plot (Diplot) (Anagnostopoulou and Tolika, 2011). Secondly, fitting tests (QQ plot and Probability plot) were applied to verify the goodness of fit of the Pareto distribution. Then the 50- and 100-year return levels of wet snow accumulation (kg/m), the maxima of 25-year long period and its return period were calculated in 12 weather stations (Békéscsaba, Budapest-Pestszentlőrinc, Debrecen, Győr, Kékestető, Miskolc, Pápa, Pécs, Siófok, Szeged, Szolnok, Szombathely) and in two periods (1965–1990 and 1991–2016). Finally, Ice Classes ranging from R1 to R10 (ISO12494, 2001) were specified for each station. R open-source statistical program was used for the calculations and visualization (R Development Core Team, 2008).

3. **Integration of wet snow forecast into the operational work:** Admirat (2008) method was chosen from the available wet snow accumulation methods. Since 2013/2014 winter wet snow

forecast has been produced with 4 NWP models (AROME, WRF, ALADIN, ECMWF) and with 3 different methods to determine precipitation phase (1. RETOP 850/1000 hPa (Hirsch, 2001); 2. FR-method based on the model microphysics (Nygaard et al., 2013); 3. Fövényi-method based on long-term statistical analysis of vertical layers (Fövényi, 2001)). The calculations are available with different snow density values (300, 400, 500 kg/m^3). A new approach in wet snow forecast is the ensemble prediction system based on high-resolution NWP model (AROME-EPS). The model sensibility to initial conditions was examined with the 11 members of the EPS system. 2 case studies are shown to demonstrate the benefits of EPS systems in wet snow forecasting.

Results and conclusions

1. **Examination of air stratification in wet snow cases**

I. I have refined the thresholds of relative topography defined by Hirsch (2008) for wet snow cases. The average relative topography is 1300 gpm, the maximum 1320 gpm, while the 25% quantile is 1260gpm.

II. I have identified that the necessary positive temperature layer for wet snow appearing directly above the ground level in 95.09% of the cases compared to the 4.91% occurrence when it forms between two negative temperature layers.

III. I have identified that the thickness of the positive temperature layer is mostly 400 meters, while a secondary maximum appears around at 800 meters.

IV. The temperature lapse rate between 1000 and 925 hPa fluctuates within a narrow interval of –0.3 and –0.4 °C/100 meter.

V. It has been proved that when wet snow occurs, the lowest air layer is usually not saturated hence the relative humidity is most often 90%–95% at the 1000 hPa pressure level.

VI. I have identified that 75% of the wet snow cases in Budapest–Pestszentlőrinc and Szeged the wind speed remained below 5m/s while exceedance of the critical wind speed of 10 m/s occurred only at 5% of the cases.

2. The calculation of the 50- and 100-year return level of wet snow, the specifications of Ice Classes

VII. Between 1965–2016 the number of wet snow cases significantly increased in Budapest–Pestszentlőrinc, Debrecen, Győr, Kékestető, Miskolc, Pápa, Pécs, Siófok, Szeged. There is a significant decrease in Szolnok. There is no change in Békéscsaba and Szombathely.

VIII. Between 1965–2016 the annual maxima of wet snow mass (kg/m) significantly decreased in Békéscsaba, Pápa and Szeged. There is no change in Budapest–Pestszentlőrinc, Debrecen, Győr, Kékestető, Miskolc, Pécs, Siófok, Szolnok and Szombathely.

IX. Between 1965–1990 there was a gradient in the R1-R10 Ice Classes from the southwest to the northeast. The most affected stations were located in the southwest, while the northeast experienced less exposure to wet snow accumulation.

X. Between 1991–2016 the previous southwest–northeast pattern in Ice Classes seemingly disappeared. The most exposed region became the northwest.

XI. At the stations in the southern regions of the country (Pécs, Szeged, Békéscsaba and Szolnok) the occurrence of wet snow accumulation decreased significantly, dropped an average 2 Ice Classes. A less remarkable decrease was observed in Szombathely and Kékestető. The change was not significant in the north, northeast regions like Budapest, Miskolc, Debrecen, or the northwest at Pápa. The level of possible wet snow accumulation increased at a low rate in the northwest region at Győr and Siófok.

XII. Between 1965–1990 and 1991–2016 there was not significant change in the relative frequency of Péczely macrosynoptic situations, focusing on those cases which resulted in wet snow accumulation.

3. Wet snow forecast using numerical weather prediction models (NWPs)

XIII. It can be declared, that the amount of wet snow (diameter (cm), weight (N/m)) can be successfully predicted with NWP models. The use of these products is now part of the forecast and weather warning practice. While previously the energy suppliers were provided with only a forecast of 3 cm or exceeding thickness of snow and a percentage of spatial coverage, now they are provided with exact, overhead wire specified wet snow forecast.

XIV. Amongst the used precipitation phase determination methods the most reliable for wet snow is the relative topography method (Hirsch, 2008) and Fövényi-method (2001). The microphysical parameterization in the models generally underestimates the volume of wet snow accumulation (FR method) due to the decreased rate of solid hydrometeors caused by the appearance of positive temperature in the models.

XV. The results related to sticking efficiency (ß) are: there was used the database of Reikningar á veðri (RÁV) (Iceland) (Nygaard et al., 2013) to refine the value of sticking efficiency, so 2 new approaches were developed:

$1/U^{0,5}$ and $\beta = \frac{1-\cos(9FR-4{,}5)}{2U^{0,4}}, if\ 0{,}5 < FR < 0{,}98,$ $otherwise$ ß $= 0$, where U is the wind speed (m/s), FR is the rate of solid hydrometeors compared to all hydrometeors from the microphysical parameterization of the model. In the dissertation the first method was applied.

XVI. Ensemble prediction system with AROME model was used to examine the sensitivity of wet snow formation for the initial conditions and as a new approach of wet snow forecast the amount of accretion was predicted by EPS system (Simon et al., 2018). The tests can be considered successful and the method can be introduced and applied in the operational work.

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